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How much weight is too much for manual lifting : determining a weight limit guideline for team-effort lifting tasks

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ABSTRACT

HOW MUCH WEIGHT IS TOO MUCH FOR MANUAL LIFTING: DETERMINING A WEIGHT LIMIT GUIDELINE FOR TEAM-EFFORT LIFTING TASKS

by
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Manual material handling is the primary cause of musculoskeletal injuries, which includes injuries related to lower back, at the workplaces in the U.S. Of all the manual material handling tasks, lifting has been the leading contributor to lower back injuries. These injuries may be induced by several risk factors associated with lifting tasks, weight of the object being lifted being one of them.

Weight limit guidelines have been developed by various groups recommending the weights that workers can lift safely without sustaining injuries. However, these guidelines are aimed to serve individual lifting tasks. Even though team lifting is a common practice in industries there is a lack of weight limit guidelines for such multi-person lifting tasks.

This paper provides a weight limit guideline for individual and team lifting tasks for an average male worker population. Tools based on biomechanical and psychophysical approaches have been utilized to determine this weight limit. The norms and practices adopted or recommended by various industries, institutions, and regulatory agencies have also been studied during the process. This guideline is likely to resolve some of the injury problems associated with lifting tasks. Though this guideline is aimed to serve 50^{th} percentile male population, similar methodology may be adopted to develop weight limits for other worker population (with different gender and anthropometry).

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To God, for blessing me with such
caring parents,
compassionate wife,
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CHAPTER 1

INTRODUCTION

1.1 Manual Material Handling Tasks: Injury/Illness Statistics

According to the Bureau of Labor Statistics (BLS), of about 1.43 million non-fatal occupational injuries and illnesses involving days away from work recorded during the year 2002 in the U.S., overexertion was the leading cause accounting for about 26.5 percent of all cases. About 87 percent of overexertion cases were associated with manual material handling tasks such as lifting, pushing-pulling, holding, carrying, turning, and wielding objects of which 54.6 percent cases involved lifting (BLS, 2004). Manual material handling tasks, in fact, are the primary causes of musculoskeletal injuries in the U.S. (Mital, 1999). Moreover, of all the manual material handling tasks, lifting and lowering have been the main contributors to the lower back injuries, accounting for 49-60 percent of lower back incidents (Eastman Kodak Co., 1986). This is in agreement with another statistics, the BLS had compiled and published in 1982 under Bulletin 2144 – 'Back injuries associated with lifting'. According to this bulletin, lifting tasks were responsible for the majority of back injuries among workers who identified the following as the factors contributing to their back injuries (Genaidya et al., 1999/2000):

- weight of the object (cited more frequently than other factors)
- body movement (identified as the next contributing factor)
- frequency of lifts

1.2 Occupational Risk Factors Contributing to Lower Back Injuries

The factors mentioned in the previous section correspond to the three main occupational risk factors responsible for musculoskeletal disorders- force, joint deviation, and repetition/duration respectively (Konz and Johnson, 2004). According to various studies these factors can contribute to low back injuries in the following manner:

Weight of lift

The rates and severity of musculoskeletal injuries increase with increase in the weight of the objects lifted. The heavy loads introduce high compressive forces on the spine resulting in low back pain and overexertion injuries (Craig et al., 2003).

Body motion

Trunk flexion may increase compressive forces on the spine and can result in increased muscular strength demand. Trunk twisting may increase spinal shear forces and is associated with decreased maximal acceptable weight of lift and lower back pain. Static bent over postures have also been associated with lower back incidents (Craig et al., 2003).

Frequency of lift

The rates and severity of musculoskeletal injuries increase with increase in the frequency of lifting/lowering tasks. High frequency lifting can result in whole-body fatigue and can also decrease the maximal acceptable weight of lift (Craig et al., 2003).

1.3 Cost of Injuries Associated with Manual Material Handling Tasks

The true cost of the overexertion injuries and disorders in the U.S., most of which occur due to manual material handling tasks, is not known. Nevertheless, the total annual societal cost, which includes direct costs due to medical services and indemnity and indirect costs due to lost productivity, costs of hiring and training replacement workers, overtime, etc., was estimated to be as high as $100 billion in 1996 (Keyserling, 2000). It is quite clear from these facts that the industries have a serious problem in their hands and need to come up with ways to bring the rate of these injuries and their costs down.

1.4 Dealing with a Real Time Manual Lifting Problem

The ideal solution to the injury problem posed by manual material handling tasks can be, not performing such tasks at all. Automation and the use of various lifting-handling aids can help eliminate the need for manual material handling tasks. However, it is not always feasible to eliminate the need for manual material handling tasks due to various reasons. In existing workplaces, the older infrastructure may make it difficult or expensive to introduce automation to reduce manual material handling tasks. In some workplaces, frequent changes in the product line during a shift or unstructured nature of jobs may make automation less desirable. The use of various handling aids, like conveyors, levelators, and hoists, can help eliminate or minimize the need for performing manual lifting and lowering. However, the use of such aids is not always preferred, especially when they are not easily accessible, difficult to use, and likely to consume more time and effort than manual handling (Eastman Kodak Co., 1986).

Under certain conditions, neither automation nor handling aids can be applied to relieve the workers of manual lifting tasks. The technicians of a New Jersey based company which manufactures instruments for pharmaceutical, biotechnological, and agrochemical companies are regularly faced with such conditions due to the typical requirements of their work assignment. When the company supplies instruments to its clients, these technicians travel to the clients' sites and install the instruments for them. Often during the course of installation, they have to lift these instruments. The size of these instruments range from 1.7 ft^3 (9"x17"x19") to 59 ft^3 (57"x35"x51") and they weigh anywhere from 25 lbs. to 500 lbs. While some of the instruments are compact and light enough for the field representatives to lift and carry, they do need assistance in lifting heavier-bulky instruments. Because these lifting tasks have to be performed at clients' sites, which may be located anywhere in the U.S., it is not feasible for the technicians to carry handling aids to these sites, which leaves them exposed to manual lifting tasks and the injury/illness risks associated with these tasks. Under such circumstances, when lifting tasks cannot be eliminated, it becomes necessary to concentrate on minimizing the injury/illness risks associated with these tasks by controlling the risk factors.

As mentioned earlier, the technicians are required to perform a few non-routine lifting tasks while installing instruments, which may weigh any where from a few lbs. to 500 lbs. Here, the frequency of lifts cannot be a limiting factor as the tasks are performed non-routinely only for a few times during a day. If proper lifting techniques are not adopted, body motion may cause musculoskeletal injuries. However, this risk factor can be controlled by learning and adopting proper lifting techniques through training. Finally, all comes to the weight of the instruments, which is one of the most obvious risk factors that can cause musculoskeletal injuries to the technicians and needs due attention.

In this thesis, an attempt is made to come up with an instrument-specific (based on the weight and dimensions of the instruments) weight limit guideline, which the technicians can follow while lifting those instruments, as a measure to control the injury risks posed by their weights.

CHAPTER 2

WEIGHT LIMIT GUIDELINES AND RECOMMENDATIONS

2.1 The Weight Limit Guidelines: Is Their Use Justified?

An obvious question that may arise while performing lifting tasks is- "How much weight can people safely lift"? To answer this question, various groups have tried to set up weight limit guidelines or recommendations for the objects to be handled. However, it is argued that setting a weight limit is neither reasonable nor prudent (Kroemer et al., 2000) and that lifting limits and guidelines oversimplify a problem that accounts for about 900,000 disabling injuries each year (LaBar, 1997). Still, one should realize that these are just the recommendations or guidelines and it requires good judgment and understanding from the part of their users in relating them with actual material handling tasks. The weight limits can, at least, serve as a good starting point for those who want to bring consistency to their back injury prevention efforts (LaBar, 1997).

Researchers have mainly used three approaches- biomechanical, physiological, and psychophysical, to derive safe and acceptable lifting capabilities, which are discussed in the following section.

2.2 Different Approaches to Derive a Weight Limit Guideline

2.2.1 Biomechanical Approach

The biomechanical approach is used to design manual material handling tasks such that the task demands are within the strength capacity and compressive force tolerance of the body. This approach is focused on determining forces and torques acting on the body during manual material handling tasks and their effects on various body parts and joints. During lifting, considerable compressive forces can be generated on the vertebrae and the vertebral discs, especially in the lower back in the L5/S1 region. The strength of the vertebral body to withstand compressive forces is the critical factor in determining the compression limits of the spine (Sanders and McCormick, 1993) and has been one of the decisive factors in setting up weight limit recommendations and guidelines.

One of the limitations of the biomechanical approach is that, the permitted load obtained using this approach remains the same irrespective of task frequency as it fails to consider the effect of fatigue on body capability to handle loads. Hence, this approach, though useful for analyzing infrequent tasks, is not suitable for high frequency tasks (Konz and Johnson, 2004). Usually, if the lifting frequencies are less than three lifts per minute, biomechanical approach is used to determine the recommended weight to be lifted (Chaffin et al., 1999).

The 3-Dimensional Static Strength Prediction Program (3-D SSPP), developed by the Center for Ergonomics at University of Michigan, is based on this approach and is discussed in greater details in Chapter 4.

2.2.2 Physiological Approach

The physiological approach is used to design manual material handling tasks such that the task demands are within metabolic and circulatory capabilities of the human body. A person's ability to lift during frequent and prolonged tasks may be limited by his/her metabolic and circulatory capabilities. This approach is focused on determining energy requirements of the task and the effects on the cardiovascular system during manual material handling tasks (Konz and Johnson, 2004).

The physiological approach is useful for analyzing manual material handling tasks that are performed frequently and for longer duration. If the lifting frequencies are more than eight lifts per minute, physiological approach is used to determine the recommended weight to be lifted, as the metabolic rate at which the body expends energy becomes the limiting factor (Chaffin et al., 1999).

The Energy Expenditure Prediction Program, developed by the Center for Ergonomics at University of Michigan, is based on this approach. However, because the use of this approach is not relevant to our requirement of setting up the weight limit guideline for non-frequent tasks, it is not discussed anymore in this thesis.

2.2.3 Psychophysical Approach

The psychophysical approach depends on subjects' perceptions of physical strain, discomfort, and fatigue associated with manual material handling tasks. In this method the subjects adjust the weight until it is acceptable for lifting over a specified time period without experiencing strain or discomfort and without becoming tired, weakened, or out of breath. The weight thus selected is considered as the maximum acceptable weight that subject can handle. Many researchers believe that this approach is one of the most appropriate for setting weight limit recommendations for manual material handling tasks (Eastman Kodak Co., 1986; Sanders and McCormick, 1993), probably because it allows the subjects to decide the load they can or want to lift.

The Maximum Acceptable Weight limit (MAWL) Tables, developed by the researchers at Liberty Mutual, are based on this approach and are discussed in greater details in Chapter 4.

Tools based on some of the above approaches have been used to evaluate the lifting tasks performed by the technicians and to derive a weight limit guideline based on those evaluations. The research plan adopted to evaluate the lifting tasks and to develop the weight limit guideline is discussed in the next chapter.

CHAPTER 3

RESEARCH PLAN

The project was divided into mainly three phases

1. Data collection
2. Lifting task evaluation and weight limit guideline development using biomechanical, psychophysical, and other tools
3. Developing recommendations to make instrument lifting tasks safer

3.1 Data Collection

A worker's ability to lift a given weight may be governed by personal factors such as gender, age, training, and fitness, as well as job factors such as object size, initial and final locations of the load, and frequency of lifts (Ayoub and Dempsey, 1999).

3.1.1 Personal Factors

The personal factors are likely to influence the maximum weight being lifted in the following manner:

Age

The load bearing capacity of spine decreases with age. Some researches have suggested that for workers over the age of 50 years, the age be considered a risk factor for manual material handling activities (Ayoub and Dempsey, 1999).

Gender

Female population is believed to have lower strength capabilities than the male population in performing manual material handling tasks. When the male and female workers perform similar physically heavy jobs, the incidence of low back pain is higher among female workers (Konz and Johnson, 2004). Some psychophysical studies have shown that, on an average, a female's lifting strength is 60 percent to 76 percent of a male's lifting strength (Ayoub and Dempsey, 1999).

Fitness

It is believed that the chances of a worker sustaining injuries while performing manual material handling tasks are lower if he/she possesses higher level of strength and fitness (Ayoub and Dempsey, 1999).

For the purpose of weight limit guideline development, it was assumed that the technicians are young, healthy, physically fit 50th percentile males.

3.1.2 Job Factors

The job factors can affect the maximum weight being lifted in the following manner:

Object size

As the size of the object increases, the distance between the center of load and the spine known as horizontal moment arm, increases. Researchers have shown that as the horizontal moment arm increases, the compression forces on the spine also increase, leading to back injuries (Davis and Marras, 2000). Thus, a bigger lighter object if held away from the body, at times, may result in greater spinal compression than a heavier compact object held closer to the body.

Initial and final locations of the load

If the object is lifted from a position very close to the floor (i.e. less then 10 inches), it becomes difficult for the worker to maintain balance when squatting (Eastman Kodak Co., 1986). Higher spinal loads and trunk moments are induced when a load is lifted from the position closer to the floor (Marras et al., 1997). The lift height of 53 inches or more is also not desirable (Eastman Kodak Co., 1986).

Task frequency

The effect of task frequency has already been discussed in Chapter 1.

The company has provided a list of instruments that are commonly handled by the technicians. This list contains information about the dimensions of these instruments and their corresponding weights. The information provided in the list was used to evaluate the lifting tasks.

Because of the unstructured nature of the lifting tasks, it was not possible to determine the initial and final load locations as well as the frequency of lifting tasks. Therefore, it was assumed that the instruments were lifted from a pallet about 6 inches high and were placed at the end of the lift on a table top about 30 inches from the floor at the frequency of one lift per 8-hour work shift.

3.2 Lifting Task Evaluation and Guideline Development

The information collected during data collection phase was utilized to evaluate the lifting tasks using various analysis tools. The tools considered for analysis were- the Revised Lifting Equation published by the National Institute of Occupational Safety & Health (NIOSH), the 3-D SSPP, and the Liberty Mutual MAWL Tables. These tools are described in greater details in the following chapter. The results obtained by evaluating the lifting tasks were used to develop a weight guideline.

3.3 Recommendations

Finally, based on the results of the lifting task evaluation, recommendations were made to make the lifting tasks safer and comfortable for the technicians to handle using various control methods. Control methods can be defined as changes made to the physical work environment, tools, equipment, work processes, and behavior of employees to eliminate or minimize hazards or minimize the consequences of hazards. Control methods can be classified into engineering controls, administrative controls, and use of personal protective equipment.

Engineering controls

Engineering controls include applying physical changes or modifications to workstations, tools, or equipment that can make material handling tasks easier for employees to perform (WISHA Services Division, 2000).

Administrative controls

Administrative controls include developing and implementing policies and procedures for safe work methods in order to reduce the severity, duration, or frequency of exposure to a hazard (WISHA Services Division, 2000). Training and educating workers on proper lifting technique is a widely used administrative control.

A low-lying object may be lifted by employing either a squat technique or a stoop technique. During a squat lifting the back is held as erect as possible (trunk flexion less than 30 degrees) with the knees flexed (knee flexion about 45 degrees) to reach to the object and lift it. In contrast, during a stoop lifting the knees are held as extended as possible (knee flexion greater than 135 degrees) with the back flexed (back flexion about 90 degrees). Of the two techniques, squat lifting is widely advocated as the 'correct technique' (van Dieën et al., 1999; Straker, 2003). Therefore, for the lifting task evaluation, it was assumed that the technicians would use the squat technique, as shown below in Figure 3.1, while lifting instruments from the pallet.

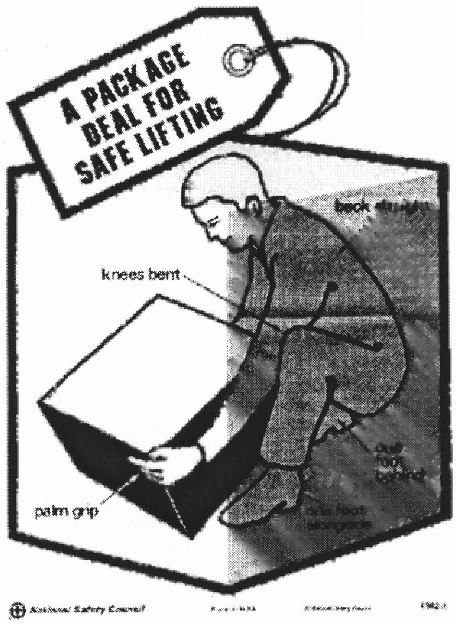

Figure 3.1 Safe lifting.

Personal protective equipment (PPE)

PPE includes gears aimed at minimizing the consequences of hazards associated with lifting tasks.

A detailed discussion of control methods can be found in Chapter 7.

CHAPTER 4

METHODS TO EVALUATE LIFTING TASKS

As mentioned in the previous chapter, a list of instruments that are commonly handled by the technicians was used to evaluate the lifting tasks.

Table 4.1 Instrument List (Categorized by the Weight-range)

Wt. range	Description	Weight (lb)	L(in)	D(in)	H(in)
21lb-30lb	FPLC Classic	Individual compo. Heaviest 24 lb			
	Lucidea Automated Slide processor	2 small compo. Each < 25 lb			
	Fraction Collectors (ALL)	All products < 30 lb			
31lb-40lb	Frac-950 Fraction Collector	37	17	24	20
	GenePix 4000B Scanner	37	16	21	14
	Spectrophotometers (ALL)	All products < 40 lb			
	AKTAprime	40	10	16	22
61lb-70lb	MultiTemp III Thermostatic Circulator	61	9	17	19
	A-900 Autosampler	65	11	21	17
	Personal Desitometer SI (All)	70	17	28	11
71lb-80lb	AKTAbasic 10	71	16	19.5	14
	AKTABasic 100	71	16	19.5	14
81lb-90lb	FarCyte Fluorescence Plate Reader	90	21	21	12
91lb-100lb	Ettan Spot Picker	91	35	24	22
	FluorImager	100	23	31	20
101lb-110lb	AKTA FPLC w/Frac-950	110	15	19	18.5
	AKTA FPLC w/Frac-900	110	15	19	18.5
121lb-130lb	Ettan Digester	121	35	24	22
150 lb	ImageMaster VDS-CL	150	32	18	38
161lb-170 lb	AKTA Explorer 100	165	20	18	24
	AKTA Explorer 10S	165	20	18	24
	AKTA Explorer 10	165	20	18	24
	AKTA Purifier 10	165	20	18	24
	AKTA Explorer 100 Air	165	20	18	24
	AKTA Purifier 100	165	20	18	24
	Ettan LC System	170	20	18	24
171lb-180 lb	AKTA Oligoppilot 10	175	20	18	24
	AKTA Oligoppilot 100	175	20	18	24
200 lb	Storm Imaging scanner	200	30	30	15
300lb	LeadSeeker Homogeneous Imaging Sys.	300			
	Ettan MALDI-ToF	300			
370 lb	Typhoon (ALL)	370	48	31	19
500 lb	MegaBase DNA Analysis system	500	41	35	31
	Lucidea Array Spotter	500	57	35	51

To begin with, the instruments in the list were organized in an ascending order based on their weights, starting from the least heavy instrument to the heaviest one. Because it was not feasible to analyze each and every instrument from the list, the list was divided into various categories based on the weight-range (for example, 21-30 lbs., 31-40 lbs., and so on). The instrument list thus obtained is shown in Table 4.1. Approximately one instrument was then selected from each category for analysis.

Thus, based on the information collected, analysis was to be performed for 50^{th} percentile male technicians (height 69.7 inches, weight 165.6 lbs.), lifting instruments shown in Table 4.1 from a pallet about 6 inches high to a table top about 30 inches above the floor using squat technique at the frequency of about 1 lift per 8-hour work shift. The tools used for analyzing the above tasks are described in the following section.

4.1 Analysis Tools

The Revised Lifting Equation is widely used in the U.S. and other countries for analyzing physical demands of two-handed manual lifting tasks. Many European countries have based their manual lifting standards on this equation. The fact that this equation is universally accepted speaks about its effectiveness in evaluating lifting tasks. Therefore, the Revised NIOSH Lifting Equation was used as the first evaluation tool for this project.

4.1.1 The Revised NIOSH Lifting Equation

In 1981, the NIOSH published the Work Practices Guide to Manual Lifting with the aim of reducing the incidences of musculoskeletal injury and illness in industry. The guide was based on the research in the fields of biomechanics, physiology, psychophysics, and epidemiology. In 1994, the guide was revised to remove some of the shortcomings of the original version. This revised guide provides the following equation for assessing the physical stress of two-handed manual lifting tasks.

$$RWL = LC \times HM \times VM \times DM \times AM \times CM \times FM$$

The equation provides the Recommended Weight Limit (RWL) for a particular task under specified conditions. In this equation the Load Constant (LC) of 51 lbs. is reduced by various multipliers which represent the level of physical stress associated with specific task characteristics. The following information is required to compute these multipliers

- the horizontal distance (H) between the center of mass of the object and the midpoint between the worker's feet
- the vertical distance (V) of the center of mass of the object from the floor
- the vertical travel distance (D) of the hands between the origin and destination of the lift
- the angle of asymmetry (A) between the worker's mid-sagittal plane and the center of mass of the load at the origin of the lift
- the type of coupling (C)
- the frequency (F) and duration of the lifting tasks

Each multiplier can attain a maximum value of 1, which represents the ideal condition (NIOSH, 1994a; Waters et al., 1998). Hence, RWL obtained under ideal conditions is 51 lbs. This indicates that under no circumstances should any healthy adult be allowed to lift a load that exceeds 51 lbs. The actual load being lifted (L) during a particular task when divided by RWL gives the Lifting Index (LI).

$$LI = L/RWL$$

The LI gives the relative estimate of the level of physical stress associated with a particular manual lifting task (OSHA, 1999). If the actual load being lifted exceeds the

RWL, the LI value will exceed 1. Any lifting task with the LI value in excess of 1 is considered undesirable for the safety of the workers. Such tasks should be redesigned using engineering and/or administrative controls. As the magnitude of the LI increases, the level of the risk increases, and a greater percentage of the workforce is likely to be at a risk of developing lifting-related low back problems (NIOSH, 1994a). The LI value in excess of 3 indicates that the weight is unsafe for most of the population to lift (OSHA, 1999).

The Revised Lifting Equation is designed to cover a wide range, about 90 percent of adult population, which includes 99 percent male and 75 percent female workforce (OSHA 1999). Though it is desirable to have weight limit recommendations that can accommodate most worker population, such recommendations may appear conservative and may not be feasible in terms of productivity and economy when need to be applied to a specific percentile and/or gender of worker population. As mentioned earlier, the technicians were assumed to be 50th percentile males. The recommended weight limits obtained by this equation may tend to underestimate the lifting potential of these technicians. Therefore, the 3-D SSPP analysis tool, that allows a better control over the anthropometrical data (range of population and gender), was selected as the next analysis tool to extract more relevant information pertinent to the requirements of the technicians.

4.1.2 The 3-D SSPP

The 3-D SSPP software, developed by Center for Ergonomics- University of Michigan, is a useful tool for evaluating the physical demands of a prescribed task. It is most applicable in analyzing slow movements used in heavy materials handling tasks, which makes it an ideal tool for evaluating the infrequent and (sometimes heavy) lifting tasks performed by the technicians. The program utilizes the biomechanical approach for evaluating the task demands. It predicts static strength requirements for lifting tasks as well as other tasks like presses, pushes, and pulls. The program provides information about the percentage of men and women who have the static strength at major body joints to perform the specified job safely, compression forces acting on the spine, static coefficient of friction required not to slip, and also determines if the balance is acceptable or not (Center for Ergonomics, 2003; Chaffin et al., 1999). For this it requires the following worker information:

- gender and anthropometric data (height and weight)
- working posture (joint angles at the ankles, knees, hip, trunk, shoulders, and elbows)
- magnitude and direction of external load acting on the hands

The user may either input the joint angles or use a cursor to point to a joint and then move it to obtain the desired posture. The program generates the three-dimensional human graphic illustrations based on the data input, which makes it easier for the user to simulate and analyze the actual tasks.

When a worker attempts to perform a manual material handling task, his/her body weight, body posture and hand loads create mechanical moments at each joint. In order to maintain the system in equilibrium, the muscles at each joint must produce enough strength to produce equal and opposite reactive moments. Based on the information provided, the program computes the strength required at various joints to maintain the system in equilibrium. The strength requirement thus computed is compared with strength capabilities of U.S. adults to estimate the percentage of male and female population capable of performing that task (Keyserling, 2000).

The University of Michigan advocates that 'professional judgment' be exercised while using this program and warns against using it as the sole determinant of worker strength performance or job designs based on that performance. It further stresses that other criteria should be considered along with this program while evaluating and designing job tasks. Therefore, the lifting tasks were also evaluated using the MAWL tables published by Liberty Mutual. Like the 3-D SSPP, these tables also provide the population percentile-specific and gender-specific information about lifting task capabilities. The results of both evaluations were then compared while finalizing the weight limit guideline.

4.1.3 The Liberty Mutual MAWL Tables

Stover Snook and his colleagues at Liberty Mutual conducted several studies on industrial workers as subjects in laboratory settings to determine psychophysical weight limits for lifting, lowering and other manual material handling tasks. The studies were aimed at measuring manual material handling efforts that could be performed repeatedly over an extended period of time, without experiencing excessive fatigue or discomfort. To achieve this purpose, the subjects were instructed to perform various two handed manual material handling tasks symmetric to the sagittal plane, working as hard as they could without getting unusually tired, weakened, overheated, or out of breath. The experimenter controlled seven variables that are considered important for determining the manual material handling task capabilities- gender, age, training, fitness, object size, initial and final locations of the load, and frequency of lifts (Ayoub and Dempsey, 1999). The subjects had control over one object characteristic- the weight, which they could adjust as per their will. The subjects adjusted weight to the maximum amount they could handle if the task were performed for a typical 8-hour work shift. The final weight thus obtained was termed as the Maximum Acceptable Weight (MAW). Liberty Mutual has published tables for MAW for various manual material handling tasks based on these studies, which provide maximum acceptable weights for various percentiles of male and female worker population (Keyserling, 2000).

4.2 Other Sources of Information

Apart from the task analysis, information was collected from various industrial sources (United Parcel Service, General Mills), institutions (NASA Glenn Research Center, the University of Medicine and Dentistry of New Jersey), and regulatory agencies (OSHA, the Department of Consumer and Employment protection- Western Australia) to determine the weight limit practices or guidelines followed or recommended by them.

The results of lifting task evaluations using different tools as well as the information obtained from various sources mentioned above are discussed in the next chapter.

CHAPTER 5

RESULTS

5.1 Analysis Results

5.1.1 The Revised NIOSH Lifting Equation Analysis

As discussed earlier, according to the Revised NIOSH Lifting Equation, the maximum weight that can be manually handled under ideal conditions is 51 lbs. Hence, this equation can not be used to evaluate lifting tasks involving instruments weighing in access of 51 lbs. As it can be seen in Table 4.1, except for the instruments belonging to first two categories, all instruments are heavier than 51 lbs., which means that this equation was not likely to serve our purpose. However, just for the curiosity it was decided to analyze the lifting tasks for instruments belonging to the first two categories. As it can be seen in Table 4.1, the dimensions of the instruments belonging to 21-30 lb. category are not known. In order to accurately analyze the weight limits, it is necessary to have this information. Thus, no instruments were selected for analysis from this category. GenePix 4000B Scanner, weighing 37 lbs., was selected for analysis from the 31-40 lb. category, as the size of this instrument is known. Analysis was performed both at the origin of the lift as well as at the destination of the lift for the ideal-most conditions. As mentioned earlier, it was assumed that the instrument is lifted from a 6-inch high pallet and placed on a tabletop 30 inches above the floor level. The results of this analysis are displayed in the Table 5.1 and are discussed in the next chapter.

Table 5.1 Results of the Revised NIOSH Lifting Equation Analysis

Step 1

Object Wt		Hand Location				Vertical Distance	Asymmetry Angle		Frequency	Duration	Coupling
L (Avg)	L(Max)	Origin		Destination			Origin	Destination	lifts/min		
		H	V	H	V	D	A	A	F		C
37	37	10	6	10	30	24	0	0	1/8 hr	8 hr	Fair

Step 2

RWL =	LC *	HM *	VM *	DM *	AM *	FM *	CM	RWL
RWL_O	51	1	0.82	0.895	1	1	0.95	35.56
RWL_D	51	1	1	0.895	1	1	1	45.65

Step 3

LI =	L /	RWL	LI	Comments
LI_O	37	35.56	1.04	Un safe
LI_D	37	45.65	0.81	

5.1.2 The 3-D SSPP Analysis

The 3-D SSPP analysis was carried out for 50th percentile males (height 69.7 inches, weight 165.6 lbs.), lifting instrument boxes from a pallet about 6 inches in height using squat technique, as shown in Figure 3.1, at the frequency of about one lift per 8-hour work shift. As mentioned earlier, studies have shown that higher spinal loads and trunk moments are induced when a load is lifted from the position closer to the floor. Therefore, analysis was performed only for the position at the start of the lift, assuming it to be the most stressful. One instrument, usually the heaviest, was selected from each weight-range category for analysis. The focus of the analysis was to determine- how many 50th percentile males can safely lift the instruments shown in Table 4.1. Lumbar-disc compression forces at L5/S1 level and body balance while lifting these loads were also determined during the analysis. The 3-D SSPP analysis for the 40 lb. instrument is shown below.

The anthropometric data was entered by accessing the 'Anthropometry' form by clicking on 'Task-Input' and then 'Anthropometry' as shown below in Figure 5.1. The data entered in the 'Anthropometry' form is shown below in Figure 5.2.

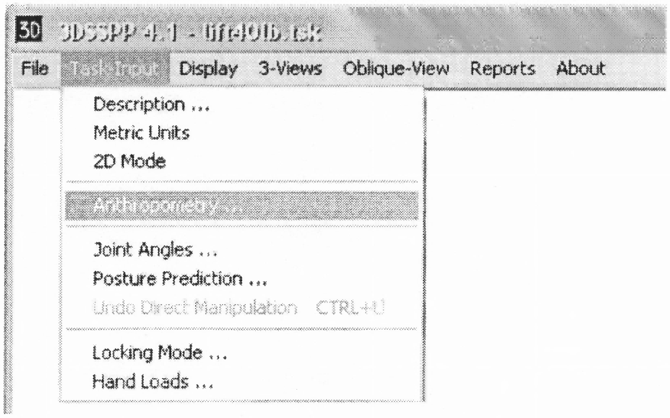

Figure 5.1 Accessing the anthropometry form.

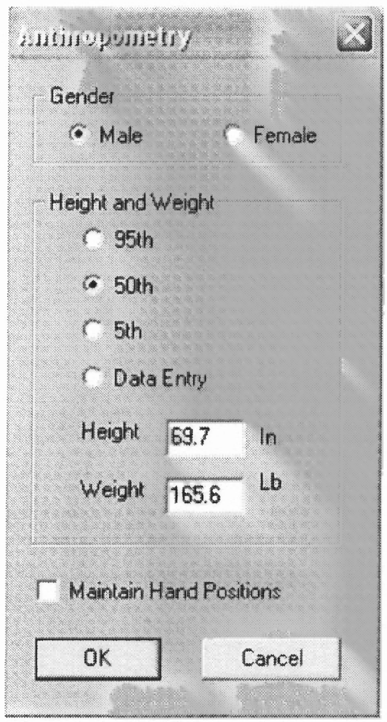

Figure 5.2 Anthropometry form.

Information about hand loads was entered by accessing the 'Hand Forces' form as shown below in Figure 5.3. The data entered in the 'Hand Forces' form is shown in

Figure 5.4. As it can be seen it is assumed that equal loads will be applied to each of the two hands.

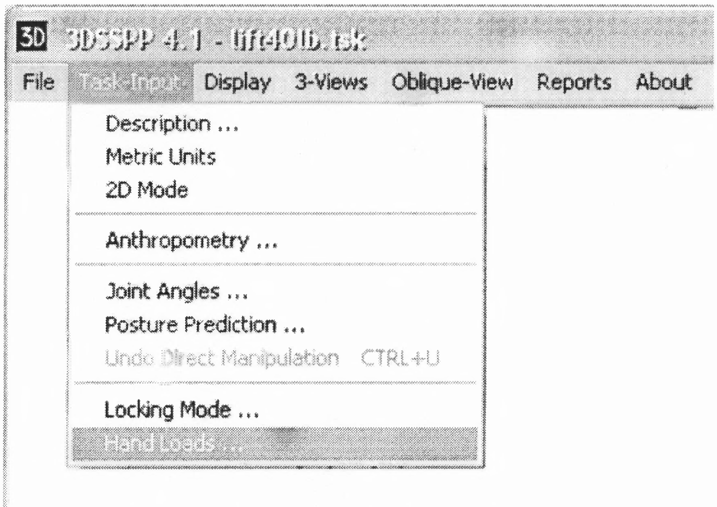

Figure 5.3 Accessing the hand forces form.

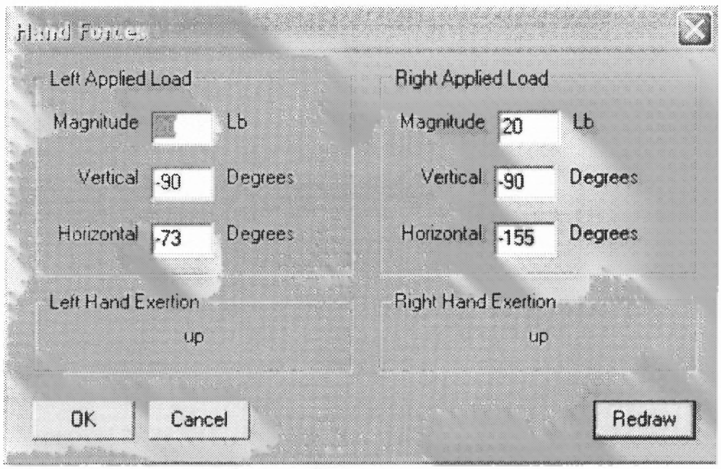

Figure 5.4 Hand forces form.

Information about the dimensions of the box was entered by accessing the 'Environment' form as shown in Figure 5.5. The 'Environment' form is shown in Figure 5.6.

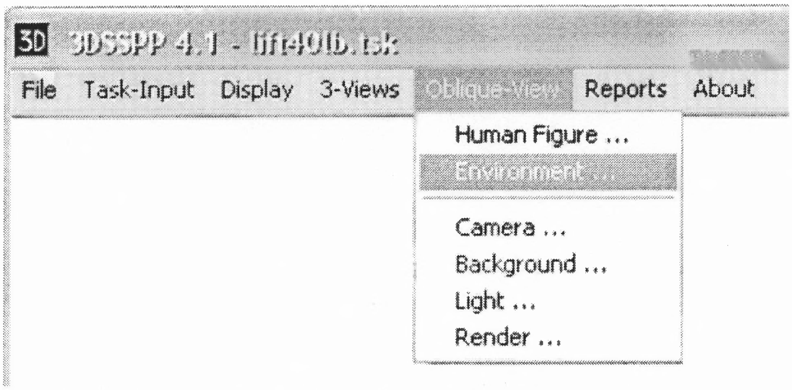

Figure 5.5 Accessing the environment form.

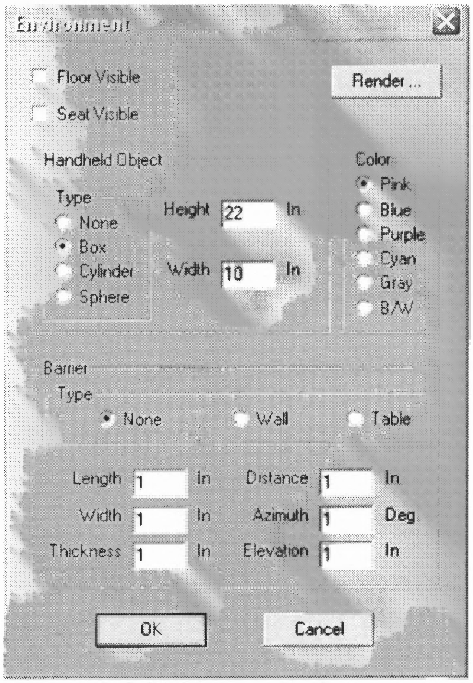

Figure 5.6 Environment form.

In the main screen, the human body is displayed in the form of stick models by default in three different views (top, front, and side view) as shown in Figure 5.7. The desired posture was obtained by pointing to various body joints shown in those stick models and then moving them in the preferred directions. The program generates a three-dimensional human graphic illustration based on the data input, which can be obtained in left side of the lower half of the main screen by accessing the 'Oblique-View Human

Figure' form as shown in Figure 5.8 and then selecting the desired options from the form. The form is shown in Figure 5.9.

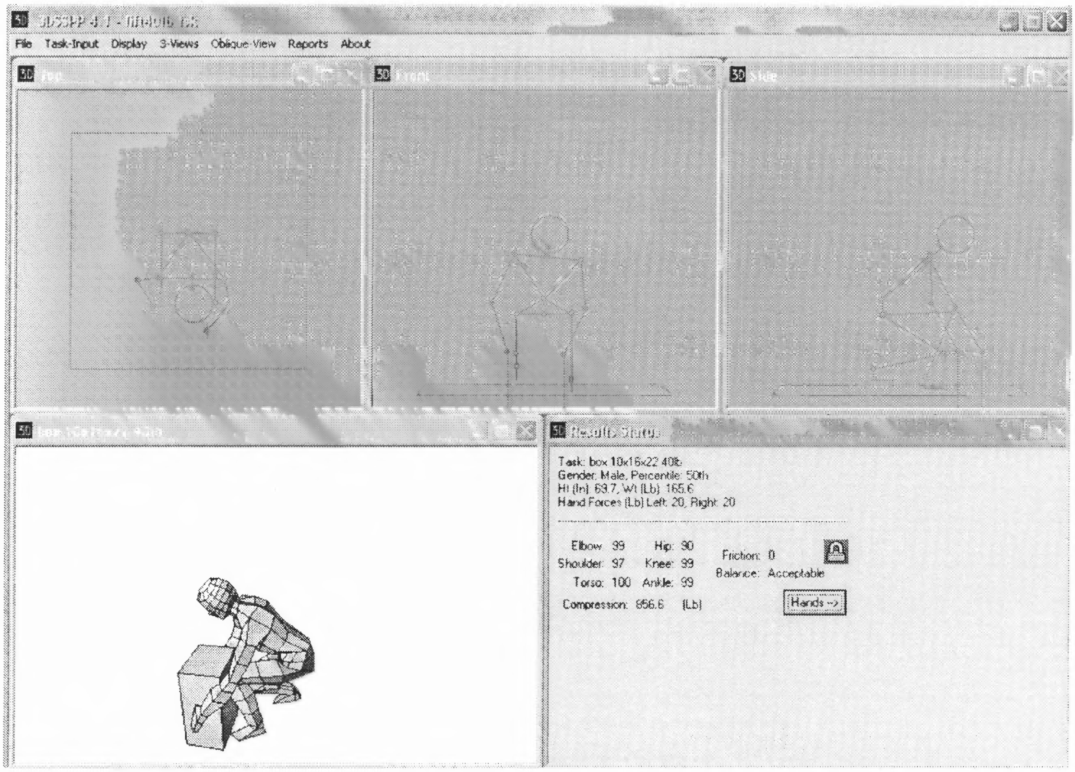

Figure 5.7 Main screen.

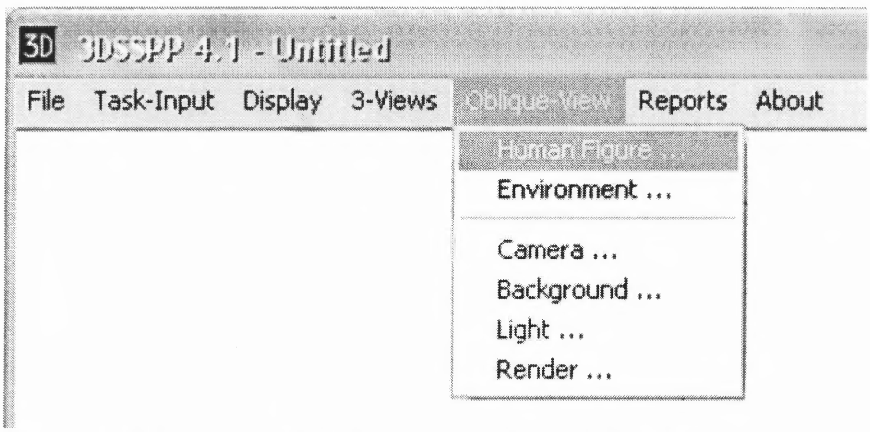

Figure 5.8 Accessing the oblique view human figure form.

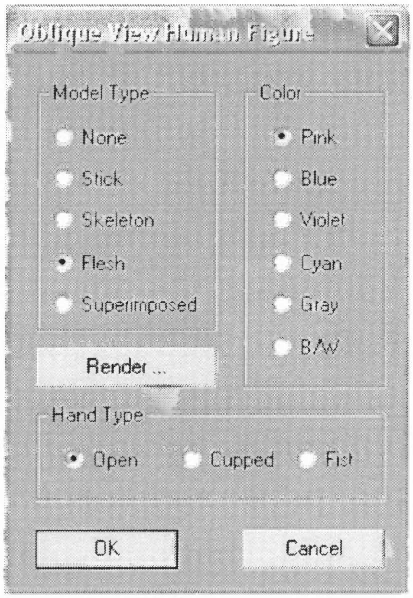

Figure 5.9 Oblique view human figure form.

The program also calculates the percent of population capable of lifting the 40 lb. instrument, lumbar-disc compression force acting at L5/S1 level, and body balance while lifting that instrument. This information can be obtained by accessing the 'Analysis Summary' screen as shown in Figure 5.10. The 'Analysis Summary' screen is shown in Figure 5.11.

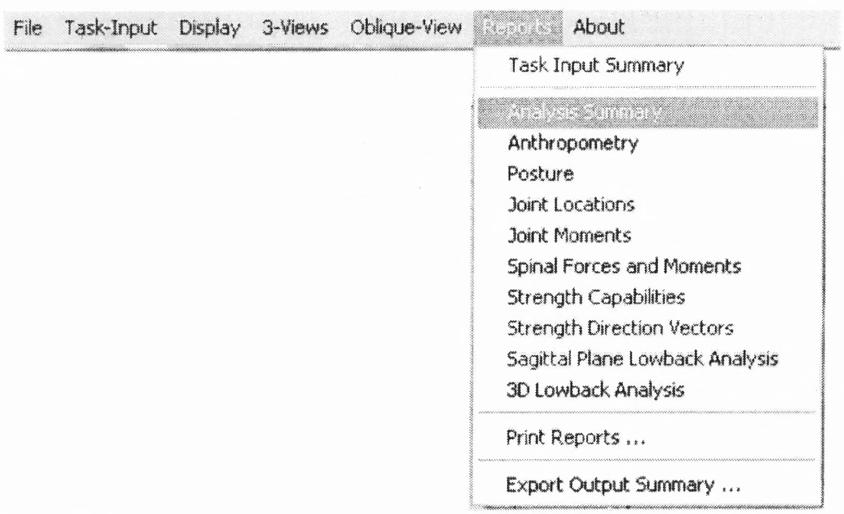

Figure 5.10 Accessing the analysis summary screen.

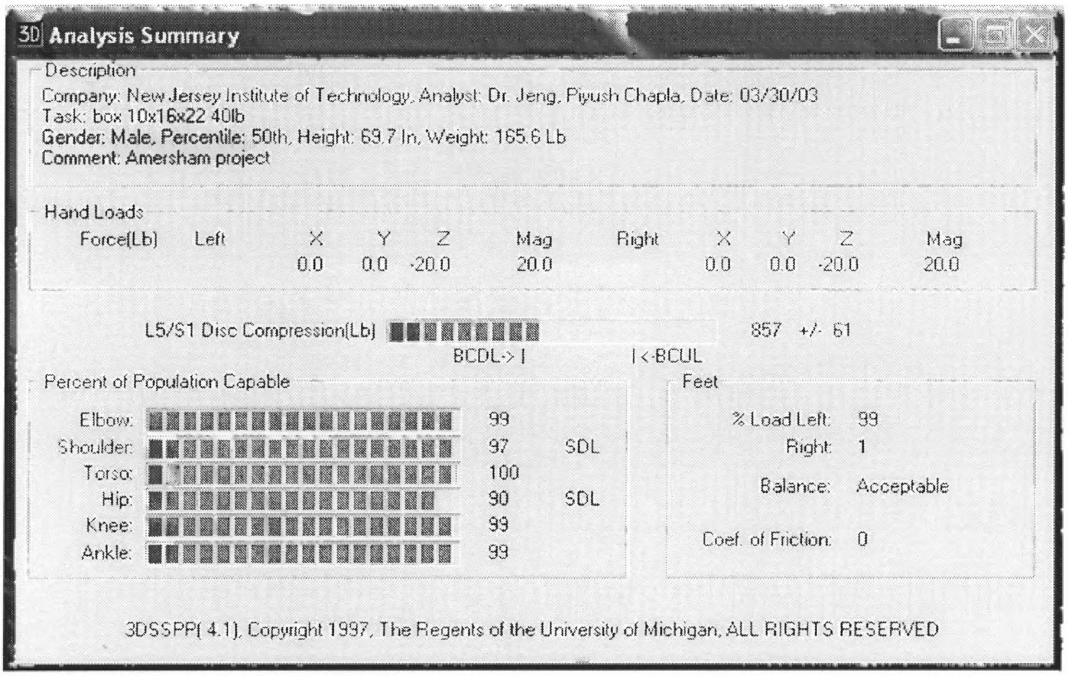

Figure 5.11 Analysis summary screen.

The results of the 3D-SSPP analysis are displayed in Table 5.2 and are discussed in the next chapter.

Table 5.2 Results of the 3-D SSPP Analysis

Wt (lb)	Dimensions (in)	Size (cu.in)	# of persons	Percent population capable* Elbow	Shoulder	Torso	Hip	Knee	Ankle	Compression (lb)	Balance
40	10x16x22	2.04	1	99	97	100	90	99	99	856.6	A
61	9x17x19	1.68	1	99	90	99	88	98	98	981	A
71	16x19.5x14	2.53	1	95	91	99	79	97	92	1202.7	A
90	21x21x12	3.06	1	98	69	99	66	98	68	1439	A
71	16x19.5x14	2.53	2	99	99	100	95	99	100	629	A
90	21x21x12	3.06	2	99	98	100	91	99	100	843.7	A
100	23x31x20	8.25	2	99	98	100	90	99	99	885.5	A
110	15x19x18.5	3.05	2	99	96	99	87	99	99	959.9	A
121	35x24x22	10.69	2	99	95	100	87	99	99	983.2	A
150	32x18x38	12.67	2	97	90	99	83	98	97	1129.6	A
165	20x18x24	5	2	90	81	99	79	97	94	1226	A
175	20x18x24	5	2	86	75	99	77	97	92	1271.1	A
165	20x18x24	5	3	99	96	99	88	98	99	960.5	A
175	20x18x24	5	3	99	95	99	87	98	98	991.2	A
200	30x30x15	7.81	3	99	93	99	84	99	99	1062.4	A
370	48x31x19	16.36	5	99	75	99	82	99	97	1139	A
500	41x35x31	25.74	6	91	69	99	84	99	99	1098.6	A
500	57x35x51	58.88	7	88	49	97	74	96	78	1338.9	A

* Percentage of 50th percentile males capable of doing the task

(shaded) Less than 80% of population with the required joint strength

A Acceptable

5.1.3 The Liberty Mutual MAWL Table Analysis

As discussed earlier, Liberty Mutual has published tables for MAWL for various manual material handling tasks based on several laboratory studies. The MAWL tables for lifting tasks provide maximum acceptable weights that various percentiles of male and female worker population can lift based on the object width, distance between the origin and destination (vertical travel distance) of the lift, and the frequency of lifting tasks. Table 5.3, which has been adapted from one of the original Liberty Mutual MAWL tables (retrieved from - http://www.undergrad.ahs.uwaterloo.ca/~ahchiang/snooktables.pdf), gives MAWL for 50th percentile male workers performing lifting tasks at the frequency of one lift per eight hours. This table was used to determine the MAW based on the width of the instruments and the distance of 29.92 inches.

Table 5.3 Liberty Mutual MAWL Table for 50th Percentile Males

			Maximal Lifting Weight (lb) Acceptable to 50 Percent Industrial Workers- 1 lift every 8 hours		
Gender	Box width (inch)	Distance (inch)	Floor level to knukle ht	Knukle ht to shoulder ht	Shoulder ht to overhead reach
Male	29.53	29.92	70.4	63.8	48.4
		20.08	74.8	70.4	55
		9.84	83.6	83.6	63.8
	19.29	29.92	83.6	63.8	57.2
		20.08	88	70.4	63.8
		9.84	99	83.6	77
	13.38	29.92	96.8	70.4	66
		20.08	101.2	79.2	74.8
		9.84	114.4	94.6	88

As seen above, the table provides MAW values for only three box widths- 29.53 inches, 19.29 inches, and 13.38 inches. Therefore, MAW values for the box widths that fall in between these values were obtained by interpolation. For example, the MAW for a box measuring 21"x21"x12" was determined to be 81.4 lbs. in the following manner.

The MAW, as seen in Table 5.3, for lifting a 29.53 inches wide box, 29.92 inches from the floor level is 70.4 lbs while that for lifting a 19.29 inches wide box through the same distance is 83.6 lbs. Thus, as the width of the box increases by 10.24 inches (29.53-19.29), the MAW reduces by 13.2 lbs. (83.6-70.4). Therefore, if the width of the box increases by 1.71 inches (21.0-19.29), the MAW should reduce by 2.20 (1.71x13.2/10.24) to 81.4 lbs. A similar approach was used to determine the MAW values for other boxes whose widths fell in between the values provided in Table 5.3.

Also, the table does not provide MAWL for box widths below 13.38 inches or in excess of 29.53 inches. Hence, MAWL values for the box widths not falling within the 13.38-29.53 inch range were obtained by extrapolation. For example, the MAW for a box measuring 10"x16"x22" was determined to be 104.3 lbs. in the following manner.

The MAW, as seen in Table 5.3, for lifting a 19.29 inches wide box, 29.92 inches from the floor level is 83.6 lbs while that for lifting a 13.38 inches wide box through the same distance is 96.8 lbs. Thus, as the width of the box decreases by 5.91 inches (19.29-13.38), the MAW increases by 13.2 lbs. (96.8-83.6). Therefore, if the width of the box decreases by 9.29 inches (19.29-10.0), the MAW should increase by 20.75 lbs (9.29x13.2/5.91) to 104.35 lbs. A similar approach was used to determine the MAW values for other boxes whose widths fell beyond the values provided in Table 5.3.

The results of the analysis are shown in Table 5.4 and are discussed in the next chapter.

Table 5.4 Results of the Liberty Mutual MAWL Analysis

Dimensions (inches)	Maximum Allowable Weight (lbs)	Weight of Instruments (lbs)	# of persons
10x16x22	104.3	40	1
9x17x19	106.6	61	1
16x19.5x14	90.9	71	1
21x21x12	81.4	90	2
23x31x20	78.8	100	2
15x19x18.5	93.2	110	2
35x24x22	77.5	121	2
32x18x38	86.5	150	2
20x18x24	86.5	165	2
20x18x24	86.5	175	3
30x30x15	69.6	200	3
48x31x19	68	370	6
41x35x31	61.5	500	8
57x35x51	61.5	500	8

5.2 Information from Other Sources

As mentioned earlier, weight limits practiced or recommended by various industrial sources, institutions, and regulatory agencies were studied to assist in determining the weight limit guideline for the technicians.

5.2.1 Industrial Practices

In order to determine industrial practices for manual lifting, information was collected from the UPS and General Mills.

The UPS employees lift loads up to 70 lbs. without any manual or mechanical assistance. This information was collected from the reliable sources in the UPS through personal contacts.

The UPS requires its customers to apply a specially designed yellow colored 'UPS heavy package sticker' on the packages weighing more than 70 lbs. The sticker has a white box in the corner where the weight of the box needs to be written. These highly visible heavy package stickers alert the UPS employees of special care they need to exercise while handling those packages (UPS, 1999-2004).

General Mills, one of the largest food manufacturers in the U.S., asks its suppliers to provide dessert mixes in 50 lb. bags instead of 100 lb. bags whenever possible. This reduces the risk of injuries induced by heavy lifting tasks (WISHA Services Division, 2000).

5.2.2 Institutional Policies

The policies for manual lifting followed by various institutions like National Aeronautical & Space Application's (NASA) Glenn Research Center and University of Medicine & Dentistry of New Jersey (UMDNJ) hospital were also studied.

As per the Safety Manual published by NASA Glenn Research Center, tasks that require lifting of more than 75 pounds at any one time, or pushing/pulling with more than 20 pounds of initial force (such as pushing a 65 pound box across the tiled floor for more than two hours per day), are considered risk factors. Such tasks are subjected to further investigation (GRC, 2002).

The UMDNJ hospital uses 18"x18"x24" boxes to collect medical wastes for disposal. It requires that the weight of wastes collected in such boxes not exceed 55 lbs. This reduces the risk of back injuries among the employees handling these boxes. This information was collected during a visit to the School of Medicine, UMDNJ.

5.2.3 Recommendations by Regulatory Agencies

The weight limit guidelines for manual lifting recommended by regulatory agencies like Occupational Safety & Health Administration (OSHA) and The Department of Consumer and Employment protection- Western Australia were also studied.

The Ergonomics Program Standard proposed by the OSHA, identifies lifting more than 75 lbs. at any one time, more than 55 lbs. more than 10 times per day, or more than 25 lbs. below the knees, above the shoulders, or at arms' length more than 25 times per day, or pushing/pulling with more than 20 lbs. of initial force (such as pushing a 65 lb. box across a tile floor for more than two hours per day), as risk factors (ECU, 2002).

The Department of Consumer and Employment protection- Western Australia suggests that the risk of back injury increases when loads over 4.5 kg (9.9 lbs.) are handled from a seated position or when loads over 16 kg (35.2 lbs.) are handled from positions other than seated. No single person in any circumstances should be required to lift, lower or carry loads over 55 kg (121 lbs.). The percentage of healthy adults who can safely handle a load decreases as the weight of the load increases from 16 kg to 55 kg. In most cases 55 kg is not a safe weight to handle. This weight range is a guideline giving an upper weight limit above which manual handling is unsafe, regardless of other factors. Similarly, not all loads below 16 kg are safe to handle in all circumstances. This weight is also a guideline, and in some circumstances loads weighing less than 16 kg are unsafe to handle (Consumer and Employment Protection, 2000).

The information on weight limit guidelines practiced or recommended by various sources studied above is summarized in Table 5.5.

Table 5.5 Weight Limits Practiced/Recommended by Various Sources

Source name	Weight limit for a single-person lift
UPS	70 lb
General Mills	50 lb (preferable weight for dessert mixes)
NASA Glenn Research Center	75 lb
UMDNJ	55 lb (for medical waste collection boxes)
OSHA	75 lb
Department of Consumer & Employment Protection	16 kg (35.2 lb)- 55 kg (121 lb)

CHAPTER 6

DISCUSSION

6.1 Interpreting the Analysis Results

6.1.1 The Revised NIOSH Lifting Equation Analysis

As discussed in the previous chapter, GenePix 4000B Scanner, weighing 37 lbs., was selected for analysis using the Revised Lifting Equation. Analysis was performed both at the origin of the lift as well as at the destination of the lift for the ideal-most conditions. It can be seen from the results table that the lifting index for the lift at the origin is exceeding the maximum allowable value of 1. This means that it is not safe for the technicians to manually lift the 37 lb. instrument at the origin of the lift. Hence, even though the LI value at destination of the lift is less than 1, meaning it is safer to lift the 37 lb. instrument at the destination, on the whole the task is considered unsafe and undesirable and should be avoided. There are three instruments in the list weighing below 30 lbs., whose dimensions are not known. If these instruments are assumed to be of the same size as GenePix 4000B Scanner, and if the same lifting posture and conditions are maintained while lifting them, the technicians should be able to lift them safely. Thus, if the results of the Revised Lifting Equation were to be followed, the technicians would not be able to lift any of the instruments from the list, except those listed in the first category. However, this recommendation is for 90 percent of adult population, which includes 99 percent male and 75 percent female workforce. The lifting capacity of 50^{th} percentile males is likely to be higher than 35.56 lbs. determined by this equation. Thus, it is advisable to use other analysis tools to extract more relevant information.

6.1.2 The 3-D SSPP Analysis

As discussed earlier, one instrument was selected from each weight-range category from Table 4.1 for the 3-D SSPP analysis. The weights selected varied from 40 to 500 lbs. The analysis was performed only for the position at the start of the lift, assuming it to be the most stressful.

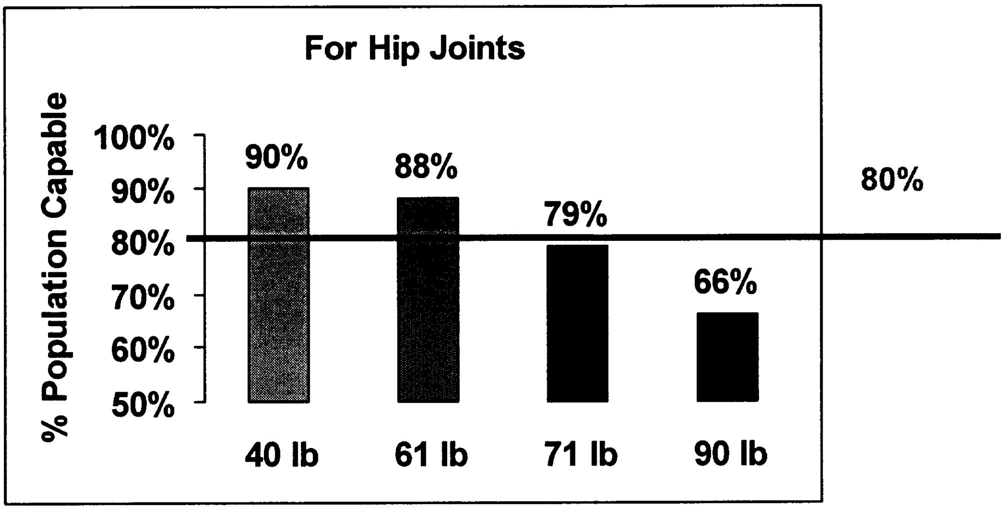

Figure 6.1 Effect of weight on hip joint strength.

It is apparent from the results table (Table 5.2) that, as the weight increases, the percentage of 50th percentile males capable of lifting that weight decreases. For example, as the weight of instruments increases from 40 to 90 lbs., fewer people have required strength at their major body joints to lift these instruments. Here, the strength of the hip joint, which corresponds to the lower back, is the limiting factor. The percentage of 50th percentile males having necessary strength at their hip joints reduces from 90 for 40 lb. load to 66 for 90 lb. load. This means that hip joints of only 66 percent of the 50th percentile males are strong enough to handle a 90 lb. load. Also, more than two out of ten 50th percentile males do not have necessary strength at their hip joints to lift a 71 lb. load.

It is also apparent from the results table that the Lumbar-disc compression force at L5/S1 level increases with an increase in the weight. The compression force on the disc increases from 856.6 to 1439 lbs. as the weight increases from 40 to 90 lbs. NIOSH has recommended a Back Compression Design Limit (BCDL) of 770 lbs. and a Back Compression Upper Limit (BCUL) of 1430 lbs. BCUL is the maximum permissible limit as recommended by NIOSH. It is clear from the results table that the L5/S1 Compression force is exceeding the BCDL value for all the loads. However, the above limits are designed to protect the majority of adult worker population, which includes 90 percent males and 75 percent females (Chaffin, 1999). Hence, it can be believed that the L5/S1 compression values obtained here should be reasonably safe for the 50th percentile males as long as they are not exceeding the BCUL value. The L5/S1 compression value for the 90 lb. load is exceeding the BCUL value.

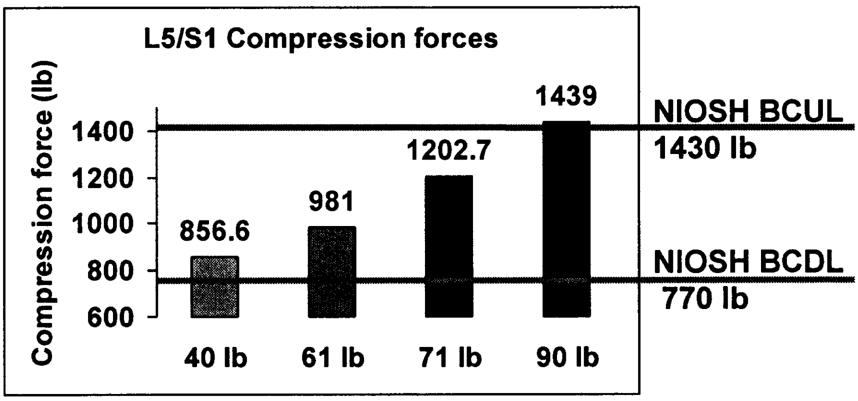

Figure 6.2 Effect of weight on L5/S1 compression force.

Studies have shown that a worker performing a lifting task is three times more likely to sustain back injuries if the task is not acceptable to at least 75 percent of the specified percentile of worker population (Snook et al., 1978). The minimum allowable strength limit for this analysis was set to 80 percent, to ensure added margin of safety. This means that the lifting task should be such that a minimum of 80 percent of the population in question has the necessary strength at their body joints to perform that task safely. As it can be seen from the results table, only 79 percent of the 50th percentile males have the necessary strength at their hip joints to lift the 71 lb. instrument, which is below the minimum allowable strength limit of 80 percent set for this analysis. Further analysis showed that if the weight of the instrument weighing 71 lbs. were reduced to 68 lbs., 80 percent of the 50th percentile males would be able to lift the load, as far as the limiting factor- the hip joint strength, is concerned, which can be seen from the 'Analysis Summary' screen shown in Figure 6.3. Therefore, the lifting weight limit for a single technician was set at 68 lbs. Any instrument weighing in access of 68 lbs. should be lifted using either manual or mechanical assistance.

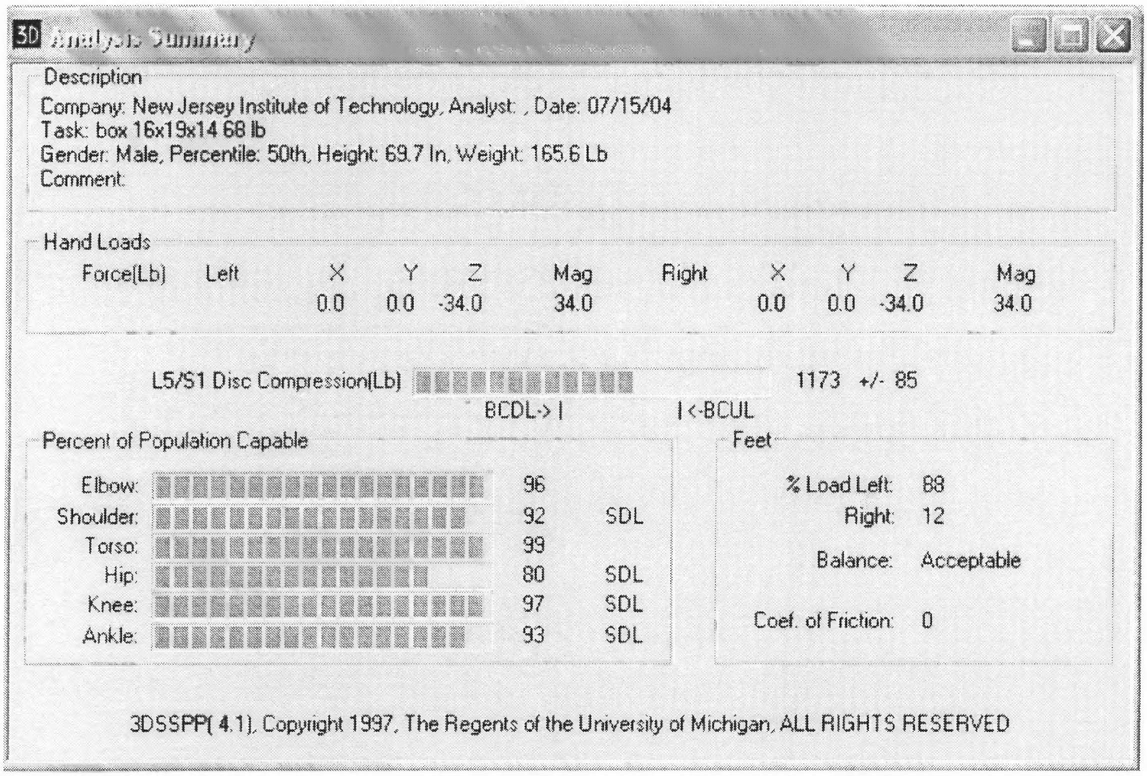

Figure 6.3 Analysis summary screen for the instrument weighing 68 lbs.

As mentioned earlier, because the lifting tasks are performed at clients' sites the technicians cannot always expect to have mechanical aids at their service. In such circumstances, manual assistance or team lifting may be adopted for lifting instruments that are heavier than 68 lbs. Therefore, for the instruments weighing in excess of 68 lbs., the 3-D SSPP analysis was carried out for the two-person lifting team.

For analyzing the two-person team lifting, it was assumed that the weight of the instruments would be equally distributed between the two 50^{th} percentile male technicians. It can be seen from the results table that when the 71 lb. instrument is lifted by two 50^{th} percentile males, about 95 percent of them are in the position to lift it. Also, considerable reduction is observed in the L5/S1 compression force, which is reduced to 628 lbs. and is well below the BCDL. Again as the weight of instruments increases from 71 to 165 lbs., the percentage of 50^{th} percentile males having adequate strength at their major body joints again decreases. The hip joint strength again becomes the limiting factor. At 165 lbs., only 79 percent of 50^{th} percentile males have the necessary strength at their hip joints to lift the load with assistance from another 50^{th} percentile male. This value is below the minimum allowable strength limit of 80 percent decided earlier. The L5/S1 compression force also increases from 628 to 1226 lbs. Further analysis showed that if the weight of the instrument weighing 165 lbs. were reduced to 160 lbs., 80 percent of the 50^{th} percentile males would be able to lift the load with the help from another 50^{th} percentile male, which can be seen from the 'Analysis Summary' screen shown in Figure 6.4. Hence, the lifting weight limit for a two-person team should be limited to 160 lbs. For instruments weighing in access of 160 lbs., the team should have three members instead of two.

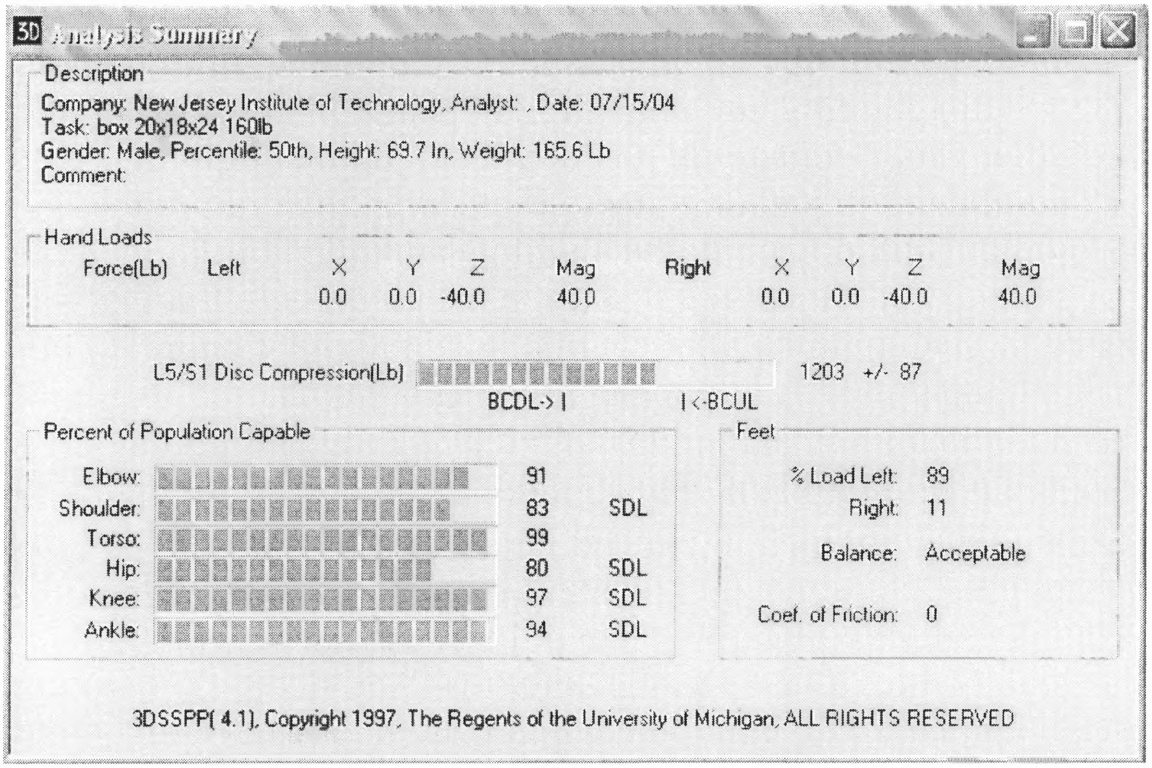

Figure 6.4 Analysis summary screen for the instrument weighing 160 lbs.

For analyzing the three-person team lifting, it was assumed that the weight of the instruments would be equally distributed among the three 50^{th} percentile males. As the third 50^{th} percentile male joins the team, about 88 percent of them are able to lift the 165 lb. instrument and the L5/S1 compression force reduces to 960.5 lbs.

At 200 lbs., 84 percent of 50^{th} percentile males are capable of handling the load, while the L5/S1 back compression force is found to be about 1062 lbs. However, it is desirable to restrict the maximum weight limit for a three-person lift to 200 lbs. If one of the members of the three-person lifting team fails to provide adequate support during the lift, it can impose considerable burden on the remaining two members. This can result in injuries as well as instrument damage. Moreover, it can be highly inconvenient if more than three persons try to handle a load, especially when the load size is small. For these reasons, it is advisable to restrict the weight limit for manual lifting to 200 lbs.

Even though it was decided to restrict the weights for manual lifting tasks to 200 lbs., lifting tasks for instruments weighing in access of 200 lbs. were analyzed to determine the number of persons required to lift them. The number of persons required to lift the listed instruments are shown in the fourth column of the results table (Table 5.2).

As mentioned earlier, the analysis shows that 80 percent of 50^{th} percentile males would be able to lift the instrument weighing 68 lbs. by themselves without any kind of assistance. Hence, one expects a two-person lifting team composed of those 80 percent 50^{th} percentile males to lift twice as much weight (68 lbs. x 2 = 136 lbs.). However, the analysis has revealed that the team could actually lift 160 lbs., 24 lbs. more than expected. This result is in agreement with that of a study which found that the weight lifted by a team was greater than the sum of weights lifted by the individual team members (Johnson and Lewis, 1989). This weight increment may be due to the change in posture while lifting objects when in team. In team lifting, the team members can hold the object closer to their body as compared to individual lifting, which reduces the horizontal moment arm between the spine and the object, resulting in an increased lifting capacity.

6.1.3 The Liberty Mutual MAWL Table Analysis

The MAW for the technicians was determined using the MAWL table for 50^{th} percentile male workers and lifting task frequency of one lift per eight hours. From the results table (Table 5.4) it is quite clear that the maximum weight a worker can lift is greatly influenced by the width of the box being lifted as well as the vertical travel distance of the lift. The results indicate that when vertical travel distance of the lift is held constant, the workers can lift more weight for boxes that are smaller in width.

As it can be seen, the third column in Table 5.4 represents the number of persons required to lift the given instrument. The procedure described below was followed to come up with the values for that column.

The MAW obtained from Table 5.4 was compared with the actual weight of the instrument. If the instrument weighed below the MAW, it was considered safe for individual lifting. If the instrument weighed above the MAW, the instrument weight was divided by the MAW. The value thus obtained was converted to the next whole number. This number represents the actual number of persons required to lift that instrument. For example, consider the instrument measuring 21"x21"x12" from Table 5.4. It weighs 90 lbs. The MAW for that instrument determined from Table 5.3 is 81.4 lbs. Because the instrument weighs greater than the MAW, it cannot be lifted by a single person. Therefore, in order to determine the number of persons required to lift it, the weight is divided by the MAW, which gives the value 1.105. This value when converted to the next whole number becomes 2, which represents the number of persons required to lift the instrument.

6.2 Interpreting the Information Collected from Other Sources

As it can be observed from Table 5.5, the weight limits for manual lifting followed or recommended by most of the sources considered, range from 50 lbs. to 75 lbs. The weight limits of 16 kg (35.2 lbs.) to 55 kg (121 lbs.) recommended by Department of Consumer and Employment protection- Western Australia appear quite high. However, these recommendations should be interpreted with great caution. Though the agency has suggested an upper weight limit of 121 lbs., it believes that in most cases it is not a safe weight to handle. This limit is applicable only when the load is within the person's capabilities, no bending or twisting is required to pick up the load, the load is compact and easy to grasp, it is held close to the trunk and not carried frequently or for long distances. The combination of these conditions is hard or almost impossible to achieve (Consumer and Employment Protection, 2000).

6.3 Finalizing the Weight Limit Guideline

As described in previous sections of this chapter, the 3-D SSPP analysis and the Liberty Mutual MAWL Table for manual lifting were used to determine the minimum number of persons required to lift the listed instruments, the results of which are displayed below in Table 6.1.

Both the 3-D SSPP and MAWL manual lifting tables, have come up with similar numbers for most of the instruments. The difference in number of persons required is observed only for two instruments, one weighing 71 lbs. and the other weighing 165 lbs. Because it was decided to restrict the manual lifting tasks to 200 lbs. only, the instruments weighing in excess of 200 lbs. are not displayed in the above table. For the 71 lb. instrument, the 3-D SSPP analysis recommends that the instrument be lifted by a two-person lifting team, as opposed to a single person lifting recommended by MAWL manual lifting table analysis. Similarly, the 3-D SSPP analysis recommends that the instrument weighing 165 lbs. be lifted by a three-person lifting team as opposed to two-person lifting team determined by MAWL manual lifting table analysis. This indicates that the margin of safety is greater in the lifting tasks evaluated by the 3-D SSPP. Hence, it was decided to establish the weight limit guideline for the technicians (50^{th} percentile males) based on the 3-D SSPP analysis conducted earlier.

Table 6.1 Number of Persons Required for Instrument Lifting

Dimensions (inches)	Weight of instruments (lbs)	# of persons 3D-SSPP	# of persons MAWL table
10x16x22	40	1	1
9x17x19	61	1	1
16x19.5x14	71	2	1
21x21x12	90	2	2
23x31x20	100	2	2
15x19x18.5	110	2	2
35x24x22	121	2	2
32x18x38	150	2	2
20x18x24	165	3	2
20x18x24	175	3	3
30x30x15	200	3	3

The final weight limit guideline, derived from the 3-D SSPP analysis, is displayed in Table 6.2.

Table 6.2 Final Weight Limit Guideline

Weight range	Number of persons required for lifting
upto 68 lbs	single-person lift
69 lbs- 160 lbs	two-person lift
161 lbs- 200 lbs	three-person lift
beyond 200 lbs	not recommended for manual lifting

The weight limit of 68 lbs. for a single person lifting also falls well within the 50-75lb. weight range practiced or recommended by various sources (industries, institutions, and regulatory agencies) studied earlier.

CHAPTER 7

RECOMMENDATIONS

The risks associated with manual lifting tasks can be eliminated or minimized (in terms of probability or severity or both) by implementing various control methods.

7.1 Engineering Controls

Engineering controls are preferable to other controls, as they can totally eliminate the risks associated with lifting tasks.

- If possible heavy/bulky instruments may be delivered to clients' sites in smaller lighter easy to handle parts. This prevents technicians from getting exposed to heavier weights. Such components can then be assembled together by the technicians during installation.

- Durable, lightweight, and easy to carry boxes may be used to pack the instruments/components for delivery. Providing handles to the boxes makes the lifting tasks easier and safer.

  According to some psychophysical studies, the maximum acceptable weight limit for lifting tasks increases if the objects being lifted are equipped with handles (Snook and Ciriello, 1991). The subjects of some of the studies perceived lesser exertion and body discomfort when they lifted boxes with handles (Drury et al., 1989). NIOSH has acknowledged the importance of coupling by incorporating the coupling multiplier in its Revised Manual Lifting Equation. Some biomechanical studies have also found the handles beneficial and have revealed that the handles can reduce the compression and shear forces placed on L5/S1 during lifting. In one such study, the maximal spinal compression forces were reduced by 6.8 percent when handles were added to the cases. The study also found that the handles were most beneficial when the objects were lifted from the position closer to the floor. For such objects placed closer to the floor, the handles would allow the subject to lift an additional weight of about 7.7 lbs. and would produce the same spinal compression force as a box without handles when placed at the same level. Also, the handles prevent the need to reach all the way to the bottom of the object to lift it. This reduces the trunk moment and allows the workers to maintain a straighter back (Davis et al., 1998).

- Wherever possible the storage or pickup area may be elevated to minimize bending.

- The need to lift or carry may be eliminated by converting the task to less stressful task like pushing or pulling. For example, the clients may be instructed to provide hand trucks, or carts to the technicians so that they can move the instruments from pallet to the installation location instead of lifting and carrying them.

7.2 Administrative Controls

Administrative controls are a subsidiary to engineering controls, when the latter fail to eliminate the risks associated with lifting tasks

- Labels may be applied on the boxes to alert the technicians of the box weight. Labels may be color-coded depending on the box weight. The weight limit guideline recommended in Table 6.2 and may be used for color-coding the labels. Different colors may be used to distinguish weight-ranges 0-68 lbs., 69- 160 lbs., 161- 200 lbs., and 201 lbs. and more. This kind of color coding not only reminds the technicians of the weight-range of the box but also of the number of persons he would require to lift that box.

  According to the Bulletin 2144 – 'Back injuries associated with lifting', mentioned earlier, about 14 percent of workers who sustained back injuries underestimated the weight before lifting. Studies have shown that when the weight of the object to be lifted is not known, a large variation is observed in force expenditure while lifting that object due to underestimation or overestimation of the weight, increasing the likelihood of back injuries (Yang and Karwowski, 1998). The likelihood of such back injures may be prevented by the use of labels described above.

- For heavier loads in excess of 200 lb., where manual lifting is not desirable, message may be conveyed through symbols as shown in Figure 7.1.

Figure 7.1 Example of a warning symbol.

- Employees should be educated about company's policies and procedures on manual lifting and should be trained for safe lifting practices. As mentioned earlier, training and educating workers on proper lifting technique is a widely used administrative control.

- When two of more employees are handling the same object, one employee may be designated to call signals. All the members of the lift should know who this is and should warn him/her if any of the members is about to relax his/her grip.

7.3 Personal Protective Equipment

Personal protective equipment are gears designed to minimize the consequences of hazards.

- Gloves may be used to lift sharp-edged objects.

- Steel-toed safety shoes or boots should be used while lifting heavy objects.

- Back-belts are not recommended, as there are conflicting views about their usefulness.

  NIOSH has made several efforts to study the effectiveness of back belts in preventing back injuries. These efforts include a review of scientific literature available on the use of back belts and a large prospective cohort study among material handlers in a retail setting. None of these studies could prove the beneficial effects of back belts in preventing back injuries. Hence, NIOSH does not recommend the workplace use of back belts as a back injury prevention measure. On the contrary it believes that the back belts may induce an increased sense of security among their users, which may encourage them to lift weights in excess of their capacities, leading to back injuries (NIOSH, 1994b; Wassell et al., 2000).

CHAPTER 8

CONCLUSION

A weight limit guideline is developed for the technicians as a measure to combat the back injury problems posed by the weights of the instruments. The minimum number of persons required to lift each of the listed instruments is also provided. The 3-D SSPP, which is based on a biomechanical approach to evaluate lifting tasks, and the Liberty Mutual MAWL tables, which are based on the psychophysical approach, were used to come up with these guidelines. The physiological approach was not considered while deciding the guideline as the tasks in question involved infrequent lifting for very short durations. The weight limit guideline was compared with the manual lifting norms and practices adopted or recommended by various industries, institutions, and regulatory agencies.

8.1 Significance

As mentioned earlier, preventing the necessity to lift is the ideal solution to resolve the injury problems associated with lifting tasks, which can be achieved through automation or the use of mechanical aids. However, many situations may occur in industries where, neither automation nor mechanical aids can be applied to eliminate the manual lifting tasks. Weight of the object being lifted is identified as the primary risk factor that can cause back injuries during the manual lifting tasks. Hence, it is essential that the workers be well-aware of their capabilities while lifting weights. According to the psychophysical approach of evaluating lifting tasks, an individual can perceive when a lifting task will increase the risk of lower back injuries or physical damage. However, this notion may not always be true. Several studies have shown that the individuals may not be good at perceiving undesirable changes in biomechanical variables such as spinal compression and moment, which have been associated with lower back problems (Jorgensen et al., 1999). Thus, the workers may not be able to perceive back stresses while performing the lifting tasks. An effort is made, by developing this weight limit guideline, to take care of workers' inabilities in perceiving undesirable changes in biomechanical variables (through the use of the 3-D SSPP). Thus, this guideline can be used to draw a biomechanical boundary within which the workers can lift weights depending upon their physiological capabilities and other conditions.

This guideline, besides setting lifting weight limits for individual workers, also recommends weight limits for team lifting. Though team lifting is a common practice in industries for handling weights that exceed the lifting capacity of individual workers, limited information is available on maximum acceptable lifting capacities of lifting teams and factors affecting maximum acceptable lifting capabilities of teams. Under such circumstances, the guideline developed here can serve as a useful tool in setting weight limits for teams and also in determining number of members required to lift objects of known weights.

8.2 Limitations

Due to the non-structured nature of the lifting tasks, several assumptions had to be made while evaluating those tasks, which is one of the limitations of the study. The effects of some of those limitations on the final weight limit are discussed below.

One of the limitations of this study is the assumption that squat technique is the 'correct technique' and that the technicians would use this technique for lifting all the instruments. There seem to be a little or no biomechanical, physiological, or psychophysical evidence to support squat technique over the stoop technique.

Psychophysical studies have revealed that the subjects tend to accept less maximum acceptable weight for the squat technique than they do for the stoop technique, probably due to greater perception of exertion associated with squat lifting (Straker, 2003). Biomechanical studies have shown that the squat technique is advantageous only when it allows the object to be lifted from the position in between the feet. Lifting the object from this position can result in reduced net moment and compression forces on the spine, reducing the back load by about one third. However, if the object can not be lifted from the position in between the feet, stoop technique is better as it produces lesser net moment and compression forces on the spine (van Dieën et al., 1999). Referring to the instrument sizes, it can be seen that some of the instruments were, in fact, too large to position them in between the feet while lifting. Hence, if the lifting tasks for such instruments were analyzed for stoop technique, it could have resulted in a reduction in L5/S1 compression forces and an increase in percentage of 50th percentile males capable of safely lifting those instruments.

For team lifting it is assumed that all the team members are 50th percentile males (height 69.7 inches, weight 165.6 lbs.) and that the load is equally shared among all the team members. This assumption may never be realized in actual conditions as it is difficult to find team members that match in terms of height, gender, and strength at the same time. Studies have shown that if the team members differ in any of these attributes, the lifting capacity of the team is greatly affected. A laboratory study has shown that the lifting capacity of a team reduces when the team members differ in stature. When the stature difference between the two team members was removed (by elevating the floor level underneath the shorter team member), the lifting capacity of the team increased significantly by five percent (Lee and Lee, 2001). Another laboratory study found the lifting capacity of a team composed of mixed gender to be lower than that of a team made up of same gender. The study showed that, while the same gender team was able to lift greater than 90 percent of the sum of their individual lifting capacities, the mixed gender team could only manage 80 percent of the same (Sharp et al., 1995). A similar study has revealed that the lifting capacity of a team is governed by the lifting capacity (strength) of the weaker team member (Rice et al., 1995).

Thus, it is quite clear from the above discussion that the weight limit of 168 lbs. set for two-person lifting team may not be achievable if all the attributes, namely- height, gender, and strength are not matched.

8.3 Final Remarks

Finally, while using the weight limit guideline developed during this project or in fact using any other similar guidelines, one should realize that in real sense it might never be possible to define a single absolute safe lifting weight. A common sense approach is required for assessing manual handling tasks. Weight should be considered, along with all other factors in the context of the task, such as actions or postures, other load characteristics, the human characteristics as well as the work environment.

APPENDIX

CALCULATIONS FOR REVISED NIOSH LIFTING EQUATION

Recommended Weight Limit RWL= LC x HM x VM x DM x AM x FM x CM

Where:	METRIC	US CUSTOMARY
Load Constant (LC)	23 kg	51 LB
Horizontal Multiplier (HM)	(25/H)	(10/H)
Vertical Multiplier (VM)	1-(.003 [V-75])	1-(.0075 [V-30])
Distance Multiplier (DM)	0.82 + (4.5/D)	0.82 + (1.8/D)
Asymmetric Multiplier (AM)	1-(.0032A)	1-(.0032A)
Frequency Multiplier (FM)	Can be determined from the table below:	

Frequency	Work Duration					
	<=1 hr		>1hr but <=2 hr		>2 hr but <=8 hr	
lifts/min	V<30+	V>=30	V<30	V>=30	V<30	V>=30
<=0.2	1	1	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.8	0.8	0.6	0.6	0.35	0.35
6	0.75	0.75	0.5	0.5	0.27	0.27
7	0.7	0.7	0.42	0.42	0.22	0.22
8	0.6	0.6	0.35	0.35	0.18	0.18
9	0.52	0.52	0.3	0.3	0	0.15
10	0.45	0.45	0.26	0.26	0	0.13
11	0.41	0.41	0	0.23	0	0
12	0.37	0.37	0	0.21	0	0
13	0	0.34	0	0	0	0
14	0	0.31	0	0	0	0
15	0	0.28	0	0	0	0
>15	0	0	0	0	0	0

Coupling Multiplier (CM) Can be determined from the table below:

Coupling Type	Coupling Multiplier	
	V<30 inches	V>=30 inches
Good	1	1
Fair	0.95	1
Poor	0.9	0.9

Calculations for lifting 37 lb. instrument:

H_o = 10 inches — HM_o = 10/10 = 1.0

V_o = 6 inches — VM_o = 1-(0.0075[30-6]) = 0.82

H_d =10 inches — HM_d = 10/10 = 1.0

V_d = 30 inches — VM_d = 1-(0.0075[30-30]) = 1.0

D = 24 inches — DM = 0.82+1.8/24 = 0.895

$A_o = 0^o$ — AM_o = 1-0.0032(0) = 1.0

$A_d = 0^o$ — AM_d = 1-0.0032(0) = 1.0

Frequency = 1 lift/8 hr — FM = 1.0

Coupling = Fair — CM_o = 0.95

CM_d = 1.0

RWL_o = 51x1.0x0.82x0.895x1.0x1.0x0.95

= 35.56 lb.

RWL_d = 51x1.0x1.0x0.895x1.0x1.0x1.0 = 45.65 lb.

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